VOLUME VIII: CHAPTER 13

METHODS FOR ESTIMATING METHANE AND NITROUS OXIDE EMISSIONS FROM MOBILE COMBUSTION

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INTRODUCTION

The purposes of the preferred methods guidelines are to describe emissions estimation techniques for greenhouse gas (GHG) sources in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. This chapter describes the procedures and recommended approaches for estimating selected GHG emissions from mobile sources.

Section 2 of this chapter contains a general description of the mobile source category. Section 3 provides an overview of the preferred and alternate methods for estimating GHG emissions from this source. Section 4 presents the preferred estimation method; Section 5 is a placeholder section for alternative estimation techniques that may be developed in the future. Quality assurance and quality control procedures are described in Section 6. References used in developing this chapter are identified in Section 7.

Transport fuels are mostly composed of hydrocarbons (HC). Under ideal combustion conditions, the HC reaction products would consist only of CO_2 and H_2O. However, under actual combustion conditions, other gases are formed because combustion is incomplete, unwanted oxidation takes place, and other trace elements are present (*e.g.*, sulfur). This chapter discusses emissions of non-carbon dioxide GHGs from mobile sources—specifically, methane (CH_4) and nitrous oxide (N_2O). (Carbon dioxide emissions from mobile sources and other fossil fuel combustion sources are addressed in Chapter 1 of this volume.) Although mobile sources also emit other GHGs, *i.e.*, carbon monoxide (CO), nitrogen oxides (NO_x), and non-methane volatile organic compounds (NMVOCs), global warming potential values have not been developed for these other gases. Thus, this chapter focuses on methods for estimating only CH_4 and N_2O emissions from mobile sources.

The reader should note before proceeding with this chapter that the calculations described can be somewhat complex and time consuming.[1] Moreover, the amounts of gases emitted from these activities are not large compared to CO_2 emissions from mobile sources. For the U.S. as a whole, CO_2 emissions from mobile sources were estimated at 445,000,000 metric tons of carbon equivalent (MTCE) in 1996, or 25 percent of total U.S. greenhouse gas emissions (U.S. EPA 1998a). For comparison, 1996 U.S. mobile source emissions of N_2O were estimated at 1.1 percent of U.S. GHG emissions, and emissions of CH_4 were estimated at 0.1 percent of U.S. GHG emissions (U.S. EPA 1998a). Nevertheless, this is an important emissions category, and many of the complex and time-consuming calculations are similar or identical to those required

[1] Much of the material in this chapter is based on IPCC 1997, Vol. 3, section 1.6 (Draft Reference Manual). The reader is referred to that document for additional information. Note, however, that many general statements in that document are based on assumptions related to engine and emission control technologies and vehicle operating conditions. The reader is encouraged to use the most current available data on vehicle activity levels and emission factors, because of both the potentially rapid change in vehicle technologies and advances in understanding of mobile source emission rates.

for developing a state criteria pollutant inventory. Thus, the reader is encouraged to contact colleagues in their state who develop the mobile source component of their state's State Implementation Plan.

This chapter provides a detailed methodology for estimating emissions from highway vehicles, because road transport accounts for the majority of mobile source fuel consumption in the U.S. It also provides a simple methodology for estimating emissions from non-road mobile sources.

2

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES AND FACTORS INFLUENCING EMISSIONS

Although there is virtually no CH_4 in either gasoline or diesel fuel, CH_4 is emitted as a combustion product whose relative abundance is influenced by fuel composition, combustion conditions, and control technology.[2] Depending on the control technologies used, CH_4 emissions may also result from hydrocarbons passing unburned or partially burned through the engine, and then affected by any post-combustion control of hydrocarbon emissions, such as catalytic converters. For highway vehicles, the emissions of unburned HC, including CH_4, are generally lowest in uncontrolled engines when the air/fuel ratio is high or "lean," which means that there is excess oxygen available relative to the quantity of hydrogen and carbon present. Such conditions favor the formation of NO_x, however. In modern three-way closed loop catalyst highway vehicles, the lowest emissions are achieved when hydrogen, carbon, and oxygen are present in exactly the right combination for complete combustion (the "stoichiometric ratio"). Conditions favoring high CH_4 emissions include aggressive driving and low speed and cold start operation. Poorly tuned highway vehicle engines may have particularly high output of total HC, including CH_4. Emissions are also strongly influenced by the engine type and the fuel combusted.

N_2O formation in internal combustion engines is not yet well understood, and data on these emissions are scarce. It is believed that N_2O emissions come from two distinct processes. In the first process, during combustion in the cylinder, N_2O is formed as NO interacts with combustion intermediates such as NH and NCO. The N_2O is then removed very rapidly in the post-flame gas by the reaction between N_2O and hydrogen. While a significant amount of N_2O may be formed in the flame, it can only survive if there is very rapid quenching of the gases, which is not common. Thus, only small amounts of N_2O are produced as engine-out emissions.

The second N_2O forming process occurs during catalytic aftertreatment of exhaust gases. The output of N_2O from the catalyst is highly temperature dependent. Prigent and De Soete (1989) showed that as the catalyst warmed up after a cold start, N_2O levels increased greatly (to 4.5 times the inlet value) at around 360° C. The emissions then decreased to the inlet level at a catalyst temperature of 460° C. Above this temperature there is less N_2O exiting the catalyst than entering it. These results demonstrate that N_2O is formed primarily during cold starts of catalyst-equipped vehicles. This explains why N_2O emissions data for the Federal Test

[2] EPA's SPECIATE model, which can be downloaded from *http://www.epa.gov/ttn/chief/software.html*, provides speciation information (*i.e.*, the relative abundance of different VOC species, including CH_4) for a wide range of source types. The reader is referred to profiles such as #1313, a 1992 estimate of gasoline vehicle exhaust composition for industry-average fuel. Because of the large global warming potential of CH_4, relative to other VOCs, and because only the exhaust emissions from gasoline and diesel vehicles can contain CH_4 (not the evaporative emissions), it is important if using information from SPECIATE that exhaust and evaporative emissions be speciated separately in emissions calculations.

Procedure (which includes a cold-start phase) are much higher than data for the U.S. Highway Fuel Economy Test (which does not include a cold start phase).

Emissions of CH_4 and N_2O from non-highway mobile sources have received relatively little study. These sources include jet aircraft, gasoline-fueled piston aircraft, farm and construction equipment, railway locomotives, boats, and ships. Except for gasoline-fueled aircraft, all of these sources are typically equipped with diesel engines. Both EPA and the California Air Resources Board are investigating emissions from these sources and developing databases and models for estimating emissions.

For more information on GHG emissions from mobile sources, the reader is referred to DeLuchi (1991).

3

OVERVIEW OF AVAILABLE METHODS

Estimating mobile source emissions is a complex undertaking that requires consideration of several parameters, including:

- the types of mobile sources (including the type of fuel combusted),
- the activity level for each type of mobile source,
- mobile source operating characteristics,
- emission controls,
- maintenance procedures, and
- fleet age.

The need for data on several parameters and the wide variety of conditions that can affect the emissions performance of mobile sources makes it impossible to develop a simple yet accurate methodology for estimating CH_4 and N_2O emissions from mobile sources. The preferred emission estimation methodology, as discussed below, does not require data on all of these elements, but is still of moderate complexity. The preferred methodology is split into two parts: (1) highway vehicles, and (2) all other mobile sources. The fundamental methodology for each part is the same, although the data sources are different.

Methods for developing greenhouse gas inventories are continuously evolving and improving. The methods presented in this volume represent the work of the EIIP Greenhouse Gas Committee in 1998 and early 1999. This volume takes into account the guidance and information available at the time on inventory methods, specifically, U.S. EPA's *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S.EPA 1998a), volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1996* (U.S. EPA 1998b).

There have been several recent developments in inventory methodologies, including:

- Publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1997* (U.S. EPA 1999) and completion of the draft inventory for 1990 – 1998. These documents will include methodological improvements for several sources and present the U.S. methodologies in a more transparent manner than in previous inventories;
- Initiation of several new programs with industry, which provide new data and information that can be applied to current methods or applied to more accurate and reliable methods (so called "higher tier methods" by IPCC); and
- The IPCC Greenhouse Gas Inventory Program's upcoming report on Good Practice in Inventory Management, which develops good practice guidance for the implementation of the 1996 IPCC Guidelines. The report will be published by the IPCC in May 2000.

Note that the EIIP Greenhouse Gas Committee has not incorporated these developments into this version of the volume. Given the rapid pace of change in the area of greenhouse gas inventory methodologies, users of this document are encouraged to seek the most up-to-date information from EPA and the IPCC when developing inventories. EPA intends to provide periodic updates to the EIIP chapters to reflect important methodological developments. To determine whether an updated version of this chapter is available, please check the EIIP site at http://www.epa.gov/ttn/chief/eiip/techrep.htm#green.

The preferred method is taken from the report by the Intergovernmental Panel on Climate Change (IPCC) entitled *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997). These methods are used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (U.S. EPA 1998a). Certain emission factors for N_2O emissions from highway vehicles have been obtained from a report by the U.S. EPA's Office of Mobile Sources (U.S. EPA 1998b).

4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

To develop estimates of CH_4 and N_2O emissions from mobile sources, information is required on the level of activity leading to emissions, the combustion technologies used, and the extent of emission control technologies employed during and after combustion. (Operating conditions during combustion also have an impact on emissions, and are reflected in the emission factor.) The basic approach for estimating emissions is presented in the following equation:

$$\text{Emissions} = \Sigma\,(EF_{abc} \times \text{Activity}_{abc})$$

where EF = emissions factor (*e.g.*, grams/kilometer traveled);
Activity = activity level measured in the units appropriate to the emission factor (*e.g.*, kilometers);
a = fuel type (*e.g.*, diesel or gasoline);
b = vehicle type (*e.g.*, passenger car, light duty truck, etc.), and
c = emission control type.

This chapter presents a methodology for estimating N_2O and CH_4 emissions from gasoline- and diesel-fueled motor vehicles,[3] as well as a methodology for estimating these emissions from airplanes, ships, boats, locomotives, and farm and construction equipment.

4.1 METHODOLOGY FOR ESTIMATING CH_4 AND N_2O EMISSIONS FROM HIGHWAY VEHICLES

Using the general equation shown above, the following steps are required to estimate motor vehicle emissions of N_2O and CH_4:

Step (1) Obtain Activity Data on Vehicle Miles Traveled

Obtain data to be used to determine the number of vehicle miles traveled (VMT) for all vehicle types. Data may be obtained from the state's highway agency or the Federal Highway Administration (FHWA). FHWA's Highway Performance Monitoring System provides annual estimates of VMT, based on traffic count data. These estimates are available from FHWA on the Internet at http://www.fhwa.dot.gov/ohim/1994/section5.htm, in the tables entitled "Vehicle-

[3] Methods are not included for estimating emissions of CH_4 and N_2O from alternative fuel vehicles (*i.e.*, vehicles fueled by natural gas, liquefied petroleum gas, ethanol, or methanol) because the number of such vehicles is relatively small and these emissions are not included in the U.S. greenhouse gas inventory (U.S. EPA 1998).

miles of travel, by State and functional system (Revised 1993) VM-2R" and "Travel distribution by vehicle type, arterial system, and State VM-4." Table VM-2R shows the number of miles of travel for each type of highway in the state. Table VM-4 shows the percentage breakdown of mileage traveled on each type of highway, for each vehicle type (passenger cars, motorcycles, buses, other 2-axle, 4-tire vehicles, single-unit 2-axle trucks with 6 or more tires, and combination trucks—split between those with single trailers and those with multiple trailers). Each table provides data for each state.

Example Vehicle miles traveled in Michigan in 1993 were as shown in the following table:

Highway Type	1993 VMT (millions)
Rural Interstate	5,852
Rural Other Principal Arterial	7,004
Rural Minor Arterial	5,603
Rural Major Collector	8,337
Rural Minor Collector	1,241
Rural Local	2,757
Urban Interstate	13,105
Urban Other Freeways and Expressways	3,959
Urban Other Principal Arterial	16,357
Urban Minor Arterial	11,947
Urban Collector	3,789
Urban Local	5,735

Step (2) Calculate the Vehicle Miles Traveled for Each Vehicle Type

Calculate the VMT for each vehicle type shown in the FHWA data. To do so, multiply the total VMT for each type of highway by the percentage of that mileage accounted for by each vehicle type. Note that the FHWA does not provide data on the percentage breakdown across vehicles of VMT for the following types of highways:

- rural major collector;
- rural minor collector;
- rural local;
- urban collector; and
- urban local.

Thus, for each of these highway types, one must select a proxy highway type to use for the percentage of VMT accounted for by each vehicle type. The most suitable proxy for the rural highway categories appears to be "rural minor arterial;" and for the urban highway categories, "urban minor arterial."

For example, to calculate the state's VMT for passenger cars, sum the products of the following multiplication steps (in each case, the VMT data are from Table VM-2R, the passenger car percentage is from Table VM-4, and proxies are used where needed for rural and urban collector and local roads):

- rural interstate VMT times passenger car percentage of rural interstate VMT;
- rural other principal arterial VMT times passenger car percentage of rural other principal arterial VMT;
- rural minor arterial VMT times passenger car percentage of rural minor arterial VMT;
- rural major collector VMT times passenger car percentage of rural minor arterial VMT;
- rural minor collector VMT times passenger car percentage of rural minor arterial VMT;
- rural local VMT times passenger car percentage of rural minor arterial VMT;
- urban interstate VMT times passenger car percentage of urban interstate VMT;
- urban other freeways and expressways VMT times passenger car percentage of urban other freeways and expressways VMT;
- urban other principal arterial VMT times passenger car percentage of urban other principal arterial VMT;
- urban minor arterial VMT times passenger car percentage of urban minor arterial VMT;
- urban collector VMT times passenger car percentage of urban minor arterial VMT; and
- urban local VMT times passenger car percentage of urban minor arterial VMT.

Use of a spreadsheet software package will make these calculations easier.

Example In Michigan, the vehicle miles traveled for passenger cars in 1993 may be calculated by multiplying the total 1993 VMT (shown in the first column of data below) by the proportion of total VMT traveled by passenger cars (shown in the second column of data below). The resulting data, for passenger car VMT, are shown in the third column of data.

Highway Type	1993 Vehicle Miles Traveled (millions)	1994 Proportion Traveled by Passenger Cars	1993 Vehicle Miles Traveled by Passenger Cars (millions)
Rural Interstate	5,852	63%	3,704
Rural Other Principal Arterial	7,004	66%	4,595
Rural Minor Arterial	5,603	67%	3,760
Rural Major Collector	8,337	67%	5,594
Rural Minor Collector	1,241	67%	833
Rural Local	2,757	67%	1,850
Urban Interstate	13,105	68%	8,938
Urban Other Freeways and Expressways	3,959	69%	2,716
Urban Other Principal Arterial	16,357	70%	11,450
Urban Minor Arterial	11,947	72%	8,602
Urban Collector	3,789	72%	2,728
Urban Local	5,735	72%	4,129
Total			58,898

Step (3) Convert the VMT Data for Use with Existing Emission Factors

Convert the VMT for each vehicle type into VMT for the vehicle types for which emission factors have been developed—*i.e.,* light duty gasoline vehicles (LDGV), light duty gasoline trucks (LDGT), heavy duty gasoline vehicles (HDGV), light duty diesel vehicles (LDDV), light duty diesel trucks (LDDT), heavy duty diesel vehicles (HDDV) and motorcycles (MC). The FHWA categories of vehicles relate to these categories as follows:

- LDGV consists of gasoline-powered passenger cars,
- LDGT consists of gasoline-powered single-unit 2-axle trucks weighing less than 8,500 pounds,
- HDGV consists of gasoline-powered single-unit 2-axle trucks with 6 or more tires, weighing more than 8,500 pounds,
- LDDV consists of diesel-powered passenger cars and light trucks,
- LDDT consists of diesel-powered single-unit 2-axle trucks,
- HDDV consists of buses and combination trucks (with single or multiple trailers), and
- MC consists of motorcycles.

Note that VMT for some FHWA vehicle categories must be apportioned to more than one category (*e.g.,* VMT for passenger cars must be apportioned between light duty gasoline-powered and diesel-powered vehicles, and VMT for gasoline trucks must be apportioned between light duty trucks and heavy duty vehicles). To make these apportionments, use the MOBILE5 (U.S. EPA 1998c) default VMT fractions shown in Table 13.4-1, or updated MOBILE5 data,[4] or state data, if available. For example, the MOBILE5 default data show that passenger cars have a VMT fraction of 0.636 (for gasoline vehicles) plus 0.004 (for diesel vehicles). Thus, the percentage of passenger car VMT attributable to gasoline vehicles is (0.636/(0.636+0.004)) or 99.34 percent; the balance of 0.66 percent (*i.e.,* 0.004/(0.636+0.004)) is attributable to diesel vehicles.

Table 13.4-1
MOBILE5 Default VMT Fractions for January 1994

Vehicle Type	VMT Fraction
LDGV	0.636
LDGT	0.26
HDGV	0.031
LDDV	0.004
LDDT	0.002
HDDV	0.059
MC	0.007
TOTAL	1.000

Source: U.S. EPA 1998c (when the model is run, it will generate these default values).

[4] Updated MOBILE5 data on VMT fractions may be obtained by obtaining the most current MOBILE5 inputs used in SIP emission inventories and running those inputs for the desired calendar year to obtain VMT fractions.

Example	In Michigan, passenger car VMT for 1993 may be allocated as follows: Total passenger car VMT in 1993: 58,898 million. LDGV VMT in 1993: 58,898 million times 99.34 percent = 58,509 million LDGV VMT in 1993 (passenger car portion only): 58,898 million times 0.66 percent = 389 million

The appendix at the end of this chapter explains the basis for the emission factors.

Step (4) Convert VMT to Vehicle Kilometers Traveled (VKT)

Convert VMT for each of the emission factor categories (LDGV through MC) to units of vehicle kilometers traveled (VKT). To do so, multiply VMT by 1.6.

Example	In Michigan for 1993, 58,509 million VMT for LDGV times 1.6 VKT/VMT = 93,600 million VKT for LDGV

Step (5) Determine Emissions Control Systems for Each Vehicle Type

The relevant emissions control systems differ by vehicle type as shown in Table 13.4-2.

Table 13.4-2
Emissions Control Systems Listed by Vehicle Type

Emission Control Technology[5]	**Vehicle Type**						
	LDGV	**LDGT**	**HDGV**	**LDDV**	**LDDT**	**HDDV**	**MC**
Uncontrolled	✓	✓	✓	✓	✓	✓	✓
Non-Catalyst Controls	✓	✓	✓				✓
Oxidation Catalyst	✓	✓	✓				
Tier 0 Three-Way Catalyst	✓	✓	✓				
Tier 1 Three-Way Catalyst	✓	✓					
LEV (low emission vehicle)	✓	✓					
Moderate Control (Diesel)				✓	✓	✓	
Advanced Control (Diesel)				✓	✓	✓	

Source: IPCC 1997

[5] Tier 0 standards, which took effect in various states throughout the 1980s, set limits on vehicle NO_x emissions. Tier 1 standards set more stringent NO_x limits, and took effect in various states in the mid-1990s. The Tier 0 limits were generally met using early three-way catalysts, while the Tier 1 standards were generally met using advanced three-way catalysts.

For each vehicle type, allocate the vehicle kilometers traveled to the relevant emission control technologies. The allocation may be developed by using state vehicle registration data showing the model year of registered vehicles.
The gasoline-powered vehicles have the most emission control technologies. Percentage breakdowns for LDGV, LDGT, and HDGV can be estimated by using the data in Tables 13.4-2 through 13.4-5. For diesel-powered vehicles, the categories are no control, moderate control (typical of 1983 US engines), or advanced control (for engines meeting US 1991 emissions standards).

Table 13.4-3
Distribution of LDGV Emission Control Technologies by Model Year, For All States but California

Model Year	Emission Control Technology				
	Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0 Three-way Catalyst	Tier 1 Three-way Catalyst
≤1972	100				
1973-1974		100			
1975		20	80		
1976-1977		15	85		
1978-1979		10	90		
1980		5	88	7	
1981			15	85	
1982			14	86	
1983			12	88	
1984-1993				100	
1994				60	40
1995				20	80
1996-1998					100

Sources: For all years through 1996, U.S. EPA 1998b. Proportions for 1997 and 1998 are assumed to be the same as those for 1996.

Example	For LDGV in Michigan in 1993, to simplify the example and avoid the need for accessing Michigan vehicle registration data, we have assumed that passenger cars and passenger car VMT in Michigan are distributed evenly over the past ten model years (*i.e.*, ten percent in each model year 1984-1993). Table 13.4-3 shows that 100 percent of LDGV in these years used Tier 0 three-way catalysts.

Table 13.4-4
Distribution of LDGT Emission Control Technologies by Model Year, For All States but California

Model Year	Emission Control Technology				
	Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0 Three-way Catalyst	Tier 1 Three-way Catalyst
≤1972	100				
1973-1974		100			
1975		30	70		
1976		20	80		
1977-1978		25	75		
1979-1980		20	80		
1981			95	5	
1982			90	10	
1983			80	20	
1984			70	30	
1985			60	40	
1986			50	50	
1987-1993			5	95	
1994				60	40
1995				20	80
1996-1998					100

Sources: For all years through 1996, U.S. EPA 1998b. Proportions for 1997 and 1998 are assumed to be the same as those for 1996.

Table 13.4-5
Distribution of HDGV Emission Control Technologies by Model Year, for All States

Model Year	Emission Control Technology			
	Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0 Three-way Catalyst
≤1981	100			
1982-1984	95		5	
1985-1986		95	5	
1987		70	15	15
1988-1989		60	25	15
1990-1998		45	30	25

Source: U.S. EPA 1998b

Table 13.4-6
California Distribution of LDGV and LDGT Emission Control Technologies By Model Year

Model Year	Emission Control Technology							
	Uncontrolled	Non-catalyst Control	Oxidation Catalyst	Tier 0 Three-way Catalyst	Tier 1 Three-way Catalyst	Low Emission Vehicle (LEV)	Ultra-Low Emission Vehicle (ULEV)	Zero Emission Vehicle (ZEV)
≤1972	100							
1973-1974		100						
1975-1979			100					
1980-1981			15	85				
1982			14	86				
1983			12	88				
1984-1991				100				
1992				60	40			
1993				20	80			
1994					90	10		
1995					85	15		
1996					80	20		
1997					73	25	2	
1998					48	48	2	2

Sources: For all years through 1996, U.S. EPA 1998b. For 1997 and 1998, ICF Consulting Group analysis.

Step (6) Estimate Emissions, in Grams, for Each Vehicle Type

For each combination of vehicle type and emission control type, multiply the vehicle kilometers traveled (VKT) by the appropriate emission factor for CH_4, from Table 13.4-7. Repeat the process for N_2O, using data from Table 13.4-8. This step will yield emissions estimated in units of grams.

Table 13.4-7
CH_4 Emission Factors for Highway Vehicles
(in g/km)

Emission Control Technology	Vehicle Type						
	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
Uncontrolled	0.135	0.135	0.270	0.010	0.010	0.060	0.260
Non-Catalyst Controls	0.120	0.140	0.125				0.130
Oxidation Catalyst	0.070	0.090	0.090				
Tier 0 Three-Way Catalyst	0.040	0.070	0.075				
Tier 1 Three-Way Catalyst	0.030	0.035					
LEV	0.025	0.030					
Moderate Control (Diesel)				0.010	0.010	0.050	
Advanced Control (Diesel)				0.010	0.010	0.040	

Source: U.S. EPA 1998b

Example (for CH_4) For Michigan in 1993, the calculation for CH_4 from LDGV is: 93,600 million VKT times 0.040 g CH_4 /km = 3,744 million g CH_4

Table 13.4-8
N_2O Emission Factors for Highway Vehicles
(in g/km)

Emission Control Technology	Vehicle Type						
	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
Uncontrolled	0.010	0.012	0.027	0.010	0.020	0.030	0.005
Non-Catalyst Controls	0.010	0.012	0.026				0.004
Oxidation Catalyst	0.032	0.042	0.087				
Tier 0 Three-Way Catalyst	0.051	0.085	0.173				
Tier 1 Three-Way Catalyst	0.029	0.040					
LEV	0.018	0.025					
Moderate Control (Diesel)				0.010	0.020	0.030	
Advanced Control (Diesel)				0.010	0.020	0.030	

Source: IPCC 1997

Example (for N_2O) For Michigan in 1993, the calculation for N_2O from LDGV is: 93,600 million VKT times 0.051 g N_2O /km = 4,800 million g N_2O

Step (7) Sum Emissions, in Grams, Across All Vehicle Types

To obtain total emissions from motor vehicles, sum CH_4 emissions estimates across all vehicle and emission control types. Repeat the process for N_2O.

Step (8) Convert from Units of Grams to Units of Metric Tons of Carbon Equivalent

Convert the values for both CH_4 and N_2O from units of grams to units of metric tons of carbon equivalent. To do so, first divide the number of grams by one million, to obtain the number of metric tons. For CH_4, multiply the number of metric tons by 12/44 (the ratio of the atomic weight of carbon to the molecular weight of CO_2) and by 21 (the global warming potential of CH_4) to obtain CH_4, emissions in metric tons of carbon equivalent (MTCE). For N_2O, multiply the number of metric tons by 12/44 and by 310 (the global warming potential of N_2O) to obtain N_2O emissions in MTCE.

Example (for CH_4)	For Michigan in 1993, the calculation for CH_4 from LDGV is: 4,800 million g CH_4 divided by 1,000,000 g/MT times 12/44 times 21 = 27,000 MTCE of CH_4.

Example (for N_2O)	For Michigan in 1993, the calculation for N_2O from LDGV is: 3,744 million g N_2O divided by 1,000,000 g/MT times 12/44 times 310 = 320,000 MTCE of N_2O.

4.2 Estimating CH_4 and N_2O Emissions from Non-Road Mobile Sources

Although mobile sources other than road vehicles account for a significant fraction of total mobile source emissions of CH_4 and N_2O, they have received relatively little study compared to passenger cars and heavy-duty trucks. Major sources of pollutant emissions among non-road vehicles include jet aircraft, gasoline-fueled piston aircraft, farm and construction equipment, railway locomotives, boats, and ships. Except for gasoline-fueled aircraft, all of these sources are typically equipped with diesel engines. Both EPA and the California Air Resources Board are now actively investigating non-road emissions and developing databases and models for estimating emissions from these sources.[6]

Using the general equation presented at the beginning of section 4, the following steps are required to estimate CH_4 and N_2O emissions from non-highway mobile sources.

[6] The EPA non-road emissions model is currently in draft form, and a series of workshops is underway to solicit comments prior to its formal release. Information on the status of this model is available on the Internet at *http://www.epa.gov/OMSWWW/nonrdmdl.htm*.

Step (1) Obtain Data on Fuel Consumption by Each Type of Non-Highway Vehicle

Obtain data on the state's fuel consumption by each type of non-highway vehicle. Data on aviation gasoline consumption are available in the U.S. Department of Energy publication *State Energy Data Book* (U.S. DOE 1997). If the state collects data on diesel fuel consumption by other types of non-highway mobile sources, the state may develop emission estimates for those other sources as well.

Example	Connecticut consumed 0.2 trillion Btu of aviation gasoline in 1995.

Step (2) Convert Units

Convert units to kilograms (kg) or megajoules (MJ) of fuel consumed (because these are the units in which the emissions factors for CH_4 and N_2O are available). To convert Btus to megajoules, first multiply the number of Btus by 1,054 joules per Btu, to obtain the number of joules. Then divide the number of joules by 1,000,000 to convert to megajoules.

Example	Connecticut's consumption of aviation gasoline in 1995 was: (0.2 trillion Btu) $\times$ (1,054 joules/Btu) = 200 trillion joules = 200 million million joules = 200 million megajoules

Step (3) Estimate Emissions, in Grams, for Each Type of Non-Highway Vehicle

Multiply the amount of fuel consumed by the appropriate emission factor for CH_4, and for N_2O. Data on emission factors from engines used in aircraft, ships, boats, railway locomotives, farm equipment (such as tractors and harvesters), and construction equipment (such as bulldozers and cranes) are shown in Table 13.4-9.

Table 13.4-9
Emission Factors for U.S. Non-Road Mobile Sources

Source	Uncontrolled Emissions	
	CH_4	N_2O
Jet Turboprop Aircraft		
G/kg Fuel	0.087	NAV
g/MJ Fuel	0.002	NAV
Gasoline (Piston) Aircraft		
G/kg Fuel	2.64	0.040
g/MJ Fuel	0.060	0.0009
Ocean-Going Ships		
G/kg Fuel	NAV	0.080
g/MJ Fuel	NAV	0.002
Boats		
G/kg Fuel	0.230	0.080
g/MJ Fuel	0.005	0.002
Locomotives		
G/kg Fuel	0.250	0.080
g/MJ Fuel	0.006	0.002
Farm Equipment		
G/kg Fuel	0.450	0.080
g/MJ Fuel	0.011	0.002
Construction and Industrial Equipment		
G/kg Fuel	0.180	0.080
g/MJ Fuel	0.004	0.002

NAV: Not Available
Source: IPCC 1997

Examples (for CH_4 and N_2O)

For simplicity in this example, we will assume that all of Connecticut's 1995 200 million megajoules of aviation gasoline was consumed by gasoline (piston) aircraft. For CH_4:

(200 million MJ) × (0.06 g CH_4/MJ) = 12 million g CH_4

To estimate the N_2O emissions:

(200 million MJ) × (0.0009 g N_2O/MJ) = 0.2 million g N_2O

Step (4) Convert from Units of Grams to Units of Metric Tons of Carbon Equivalent

Convert the values for both CH_4 and N_2O from units of grams to units of metric tons of carbon equivalent. To do so, first divide the number of grams by one million, to obtain the number of metric tons. For CH_4, multiply the number of metric tons by 12/44 (the ratio of the atomic weight of carbon to the molecular weight of CO_2) and by 21 (the global warming potential of CH_4) to obtain CH_4 emissions in metric tons of carbon equivalent (MTCE). For N_2O, multiply the number of metric tons by 12/44 and by 310 (the global warming potential of N_2O) to obtain N_2O emissions in MTCE.

Examples (for CH_4 and N_2O)

To convert the 12 million grams of CH_4 emissions from Connecticut's 1995 consumption of aviation gasoline to units of MTCE:

(12 million g CH_4) $\times$ (metric ton/million grams) = 12 metric tons CH_4
(12 metric tons CH_4) $\times$ (12/44) $\times$ 21 = 69 MTCE of CH_4

To convert the 0.2 million grams of N_2O emissions:

(0.2 million g N_2O) $\times$ (metric ton/million grams) = 0.2 metric tons N_2O
(0.2 metric tons N_2O) $\times$ (12/44) $\times$ 310 = 17 MTCE of N_2O

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ALTERNATE METHODS FOR ESTIMATING EMISSIONS

No alternate methods have yet been approved by the Greenhouse Gas Committee of the Emission Inventory Improvement Program.

6

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) are essential elements in producing high quality emission estimates and should be included in all methods to estimate emissions. QA/QC of emissions estimates are accomplished through a set of procedures that ensure the quality and reliability of data collection and processing. These procedures include the use of appropriate emission estimation methods, reasonable assumptions, data reliability checks, and accuracy/logic checks of calculations. Volume VI of this series, *Quality Assurance Procedures*, describes methods and tools for performing these procedures.

6.1 DATA ATTRIBUTE RANKING SYSTEM (DARS) SCORES

DARS is a system for evaluating the quality of data used in an emission inventory. To develop a DARS score, one must evaluate the reliability of eight components of the emissions estimate. Four of the components are related to the activity level (*e.g.*, the number of vehicle miles traveled). The other four components are related to the emission factor (*e.g.*, the amount of N_2O emitted per vehicle mile traveled). For both the activity level and the emission factor, the four attributes evaluated are the measurement method, source specificity, spatial congruity, and temporal congruity. Each component is scored on a scale of zero to one, where one represents a high level of reliability. To derive the DARS score for a given estimation method, the activity level score is multiplied by the emission factor score for each of the four attributes, and the resulting products are averaged. The highest possible DARS composite score is one. A complete discussion of DARS may be found in Chapter 4 of Volume VI, *Quality Assurance Procedures*.

This section provides DARS scores for four categories of mobile sources:

1. CH_4 emissions from highway vehicles,
2. N_2O emissions from gasoline-fueled highway vehicles,
3. N_2O emissions from diesel-fueled highway vehicles, and
4. CH_4 and N_2O emissions from non-highway mobile sources.

The DARS scores are organized in this way because, within each category, the data sources and emission factors are similar across all types of vehicles and emission control technologies, and the sources and extent of uncertainty are also similar.

The DARS scores provided here are based on the use of the emission factors provided in this chapter, and activity data from the sources referenced in the various steps of the methodology. If a state uses state data sources for activity data, the state may wish to develop a DARS score based on the use of state data.

TABLE 13.6-1

DARS SCORES: CH_4 EMISSIONS FROM HIGHWAY VEHICLES

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	8	The emission factors are based on a sophisticated model that uses measured inputs.	6	Vehicle miles traveled are estimated based on sampling.	0.48
Source Specificity	10	The emission factors were developed specifically for the various types of vehicles and their emission control technologies.	9	Vehicle miles traveled are very closely correlated to the emission activity.	0.90
Spatial Congruity	7	Emission factors were developed for the U.S., not for individual states; spatial variability is expected to be moderate.	10	States use state-level data on vehicle miles traveled.	0.70
Temporal Congruity	7	Emission factors were developed based on assumptions reflecting conditions at one point during the year; temporal variability is expected to be low to moderate.	7	As of late 1998, FHWA data on vehicle miles traveled were available only for 1994; temporal variability over a four-year period is expected to be low to moderate.	0.49
				Composite Score	0.64

TABLE 13.6-2

DARS SCORES: N_2O EMISSIONS FROM GASOLINE-FUELED HIGHWAY VEHICLES

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	8	The emission factors are based on measurement of emissions from a small sample of vehicles.	6	Vehicle miles traveled are estimated based on sampling.	0.48
Source Specificity	10	The emission factors were developed specifically for the various types of vehicles and their emission control technologies.	9	Vehicle miles traveled are very closely correlated to the emission activity.	0.90
Spatial Congruity	7	Emission factors were developed for the U.S., not for individual states; spatial variability is expected to be moderate.	10	States use state-level data on vehicle miles traveled.	0.70
Temporal Congruity	7	Emission factors were developed based on testing over less than a full year; temporal variability is expected to be low to moderate.	7	As of late 1998, FHWA data on vehicle miles traveled were available only for 1994; temporal variability over a four-year period is expected to be low to moderate.	0.49
				Composite Score	0.64

TABLE 13.6-3

DARS SCORES: N_2O EMISSIONS FROM DIESEL-FUELED HIGHWAY VEHICLES

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	8	The emission factors are based on a sophisticated model.	6	Vehicle miles traveled are estimated based on sampling.	0.48
Source Specificity	7	The emission factors were developed specifically for the various types of vehicles, but assumed moderate control for all vehicles; the expected variability is low to moderate.	9	Vehicle miles traveled are very closely correlated to the emission activity.	0.63
Spatial Congruity	7	Emission factors were developed for Europe, not for states in the U.S.; spatial variability is expected to be moderate.	10	States use state-level data on vehicle miles traveled.	0.70
Temporal Congruity	7	Emission factors were developed based on assumptions reflecting conditions at one point during the year; temporal variability is expected to be low to moderate.	7	As of late 1998, FHWA data on vehicle miles traveled were available only for 1994; temporal variability over a four-year period is expected to be low to moderate.	0.49
				Composite Score	0.58

TABLE 13.6-4

DARS SCORES: CH_4 AND N_2O EMISSIONS FROM NON-HIGHWAY MOBILE SOURCES

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	5	The emission factors were based on limited data from the literature on emissions from highway mobile sources, and an assumption that emissions from non-highway mobile sources are equivalent, being proportional to fuel consumption.	4	Fuel consumption is estimated based on an allocation of total U.S. consumption across all states.	0.20
Source Specificity	6	The emission factors were developed specifically for the various types of mobile sources, but did not account for variation within each type of mobile source; the variation is assumed to be moderate to high.	9	Fuel consumption is very closely correlated to the emission activity.	0.54
Spatial Congruity	7	Emission factors were developed for the U.S., not for individual states; spatial variability is expected to be moderate.	10	States use state-level data on fuel consumption by each type of non-highway mobile source.	0.70
Temporal Congruity	7	The underlying emissions data (for highway mobile sources) were obtained by testing over less than a full year; temporal variability is expected to be low to moderate.	10	States use annual data to estimate annual emissions.	0.70
				Composite Score	0.45

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REFERENCES

DeLuchi, Mark. 1991. *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity,* Argonne National Laboratory, November 1991.

IPCC. 1997. IPCC Guidelines for National Greenhouse Gas Inventories, 2 volumes: Vol. 2, Workbook; Vol. 3, Draft Reference Manual. Intergovernmental Panel on Climate Change, Organization for Economic Co-Operation and Development. Paris, France. Internet address: http://iea.org/ipcc/general/inus1.htm

Prigent, M. and G. De Soete. 1989. *Nitrous Oxide N_2O in Engines Exhaust Gases- A First Appraisal of Catalyst Impact.* SAE Paper No. 890492. SAE International, Warrendale, PA.

U.S. Department of Energy (U.S. DOE 1997). *State Energy Data Report* DOE/EIA-0214(95). Internet address: http://www.eia.doe.gov (click on "State Energy Data").

U.S. EPA (U.S. Environmental Protection Agency). 1999. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 1997*. EPA 236-R-99-003. Internet address: http://www.epa.gov/globalwarming/inventory/1999-inv.html.

U.S. Environmental Protection Agency (U.S. EPA 1998a) *Inventory of U.S. Greenhouse Gas Emissions and* http://www.epa.gov/globalwarming/inventory/1998-inv.html.

U.S. EPA 1998b. *Emissions of Nitrous Oxide from Highway Mobile Sources*, EPA-R20-R-98-009. Internet address: http://www.epa.gov/oms/climate.htm

U.S. EPA 1998c. *MOBILE5* (computer model). Internet address: http://www.epa.gov/oms/models.htm

U.S. EPA. 1989. *User's Guide to Mobile4 (Mobile Source Emission Model)*. Emission Control Technology Division, Ann Arbor, MI.

Weaver, C.S and S.H. Turner. 1991. Memorandum to Jane Leggett U.S. EPA and Craig Ebert, ICF, Incorporated, June 3, 1991.

8

APPENDIX

HOW EMISSION FACTORS WERE DEVELOPED

This section discusses how the CH_4 and N_2O emission factors for highway vehicles were developed. The discussion in this section is adapted from Weaver and Turner (1991). States are encouraged to use more appropriate in-state emission factors if available.

Emission Factors for CH_4 Emissions

The emission factors for CH_4 emissions from highway vehicles, shown in Table 13.4-7, have been published in IPCC (1997), and were developed in 1991 based on the U.S. EPA's MOBILE4 model (U.S. EPA, 1989). (The MOBILE model has also generated emission factors for NOx, CO, and NMVOCs, but only the emission factors for CH_4 are discussed here.) MOBILE5a, an updated version of the model, was released in 1993, and another major revision has been under development for several years.[7] The on-going effort to improve MOBILE and related models is indicative of both the uncertainties in the models and the complexities of addressing evolving vehicle technologies, fuels, and control programs. To date, most of the testing and modeling effort has addressed emissions from light duty vehicles; thus, the emission factor estimates for heavy duty vehicles are considered less reliable. The following discussion describes the IPCC/MOBILE4-based emission factors.

MOBILE calculates emission factors for U.S. gasoline- and diesel-fueled vehicles based on the year in which they were manufactured. To develop emission factors for different emission control technology types, MOBILE performs calculations for specific model years during which U.S. vehicles were equipped with the technology in question. To reflect normal in-use deterioration over the vehicle's life, emission factors were calculated for each vehicle type when the vehicles were five years old, or approximately halfway through their useful lives. For example, estimates of uncontrolled passenger vehicle emissions for model year 1963 vehicles were based on MOBILE4 results in calendar year 1968. Similarly, emissions estimates for 1990 model year vehicles equipped with advanced emission control technology were based on results under 1995 operating conditions. Table 13.8-1 shows the U.S. vehicle model years chosen to represent specific technology types.

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[7] MOBILE5a is the currently recommended version, and is available from the EPA's Internet site on emissions modeling: *http://www.epa.gov/oms/models.htm* (MOBILE5b incorporates additional revisions but states have not been required to recalculate MOBILE5a-based inventories). MOBILE6 is under development (with an anticipated release in 1999), and incorporates a number of substantial changes in the emission calculations. Emission estimates based on MOBILE5a are consistently higher than those based on MOBILE4—by as much as 59 percent for some pollutants and vehicle types. The mandated preparation and submittal to EPA of 1996 emission inventories (see *http://www.epa.gov/oar/oaqps/efig/ei/*) may also provide useful data for mobile source emission calculations.

The emission factors calculated by MOBILE4 are affected by the assumptions used in the model regarding average speeds, ambient temperature, diurnal temperature range, altitude, fuel volatility, and the presence or absence of programs to require inspection and maintenance and to prevent tampering. Since it would not be possible to represent, in a single set of factors, the diversity in these conditions among states, the conditions chosen for the modeling were "typical" values of 75° F, with a diurnal range from 60° to 85° F, and Reid vapor pressure of gasoline at 9.0 PSI (62 kPa). Average speed was taken as the MOBILE4 default of 19.5 mph, typical of uncongested urban driving. Also assumed were effective inspection and maintenance, and anti-tampering programs, which would help ensure that the vehicle emission controls were in place and functioning as designed. (This assumption may result in some under-estimation of *actual* emissions from emission-controlled vehicles, because not all vehicles are subject to such effective standards.)

Table 13.8-1

Emission Control Technology Types and U.S. Vehicle Model Years Used to Represent Them

Technology	Model Year
Gasoline Passenger Cars and Light Trucks	
Uncontrolled	1963
Non-catalyst controls	1972
Oxidation catalyst	1978
Tier 0 regulations	1983
Tier 1 regulations	1990
Heavy-Duty Gasoline Vehicles	
Uncontrolled	1968
Non-catalyst control	1983
Tier 1 regulations	1991
Diesel Passenger Cars and Light Trucks	
Uncontrolled	1978
Moderate control	1983
Advanced control	1990
Heavy Duty Diesel Vehicles	
Uncontrolled	1968
Moderate Control	1983
Advanced control	1991
Motorcycles	
Uncontrolled	1972
Non-catalyst controls	1990

Changes in these input assumptions would change the resulting emission factors. For example, emission factors increase markedly at low temperatures. Emissions per mile also tend to rise with decreasing average speed, due mostly to the increase in fuel consumption per mile.

Emission Factors for N_2O Emissions

The emission factors for N_2O, shown in Table 13.4-8, were developed by the U.S. EPA's Office of Mobile Sources (U.S. EPA 1998b).

The U.S. EPA OMS used several different approaches to develop the N_2O emission factors presented in Table 13.4-8 (U.S. EPA 1998b). Emission factors for Tier 0 and earlier gasoline-fueled vehicles were determined primarily from published literature. Emission factors for Tier 1 gasoline-fueled vehicles and for LEVs were developed using data from tests of 23 vehicles conducted at EPA's National Vehicle and Fuel Emissions Laboratory in June and July 1998. Emission factors for gasoline-fueled trucks were based on emission factors for passenger vehicles. The OMS report noted that the limited data on emissions from gasoline-fueled trucks indicated that light duty trucks emit more N_2O per mile than do gasoline-fueled passenger vehicles. The report concluded that, in the absence of a better alternative, emission factors for passenger vehicles should be extrapolated and applied to light trucks, in proportion to their fuel economy. To conduct the extrapolation, the OMS report used fuel economy data published in IPCC 1997. The report noted that while the fuel economy data could likely be improved, only the ratios of fuel economy for various vehicle classes were used to conduct the extrapolation.

For diesel-fueled vehicles, the OMS report noted that data were limited and that European researchers had greater experience with diesel vehicles; for these reasons, OMS recommended using the European values for N_2O emissions from IPCC 1997.

DISCUSSION OF TYPES OF HIGHWAY VEHICLES, AND ASSOCIATED CONTROL TECHNOLOGIES

Light-duty gasoline passenger cars. The U.S. EPA considers a passenger car to be any vehicle with rated gross vehicle weight less than 8,500 lb (3,855 kg) designed primarily to carry 12 or fewer passengers, and not possessing special features such as four wheel drive for off-road operation. Emission estimates are shown for five levels of control technology. These technology levels range from completely uncontrolled through non-catalyst emission controls, oxidation catalysts, and two levels of three-way catalyst control (Tier 0 and Tier 1). Non-catalyst emission controls include modifications to ignition timing and air-fuel ratio to reduce emissions, exhaust gas recirculation (EGR), and air injection into the exhaust manifold. Oxidation catalyst systems normally include many of the same techniques, plus a two-way catalytic converter to oxidize HC and CO. The Tier 0 three-way catalyst results are representative of those for vehicles sold in the U.S. in the early to mid '80s, which were mostly equipped with carburetors having electronic “trim.” The Tier 1 three-way catalyst values are based on vehicles using current U.S. technology, *i.e.*, electronic fuel injection under computer control.

Light-duty gasoline trucks. Light-duty trucks are defined as vehicles having rated gross vehicle weight less than 8,500 lb (3,855 kg), and which are designed primarily for transportation of cargo or more than 11 passengers at a time, or which are equipped with special features for off-road operation. They include most pickup trucks, passenger and cargo vans, and four-wheel drive vehicles. The engine technologies used in these vehicles are similar to those used in passenger cars, but these vehicles usually have larger engines, poorer fuel economy, and somewhat higher emissions. The emission control technologies are the same as those for gasoline passenger vehicles.

Heavy-duty gasoline vehicles. A heavy-duty vehicle is defined as one having a manufacturer's gross vehicle weight rating exceeding 8,500 lb (3,855 kg). In the U.S., this includes a number of models of large pickups and vans, along with specialized trucks using pickup and van chassis, as well as the larger “true” heavy-duty trucks, which typically have gross vehicle weights of 8 tons or more. In the U.S., the large pickups and vans in this category greatly outnumber the heavier trucks; thus, the emission factors calculated by MOBILE4 are more representative of large pickups and vans. This is also reflected in the fuel economy estimate for these vehicles of 6.1 miles/gal.

Estimates were developed for three levels of emission control technology: uncontrolled, non-catalyst emission controls, and Tier 0 three-way catalyst technology. Non-catalyst emission controls include control of ignition timing and air-fuel ratio to minimize emissions, exhaust gas recirculation (EGR), and air injection into the exhaust manifold to reduce HC and CO emissions. Tier 0 three-way catalyst technology includes electronically-controlled fuel injection, EGR, air injection, and electronic control of ignition timing, as well as the catalyst itself.

Light-duty diesel passenger cars. The U.S. EPA defines a diesel passenger car similarly to its gasoline counterpart, as a vehicle designed primarily to carry fewer than 12 passengers, with a manufacturer's rated gross vehicle weight less than 8,500 lb (3,855 kg), and not possessing special features such as four wheel drive for off-road operation. Estimates are shown for three levels of emission control technology, ranging from uncontrolled, through moderate emissions control (achieved by changes in injection timing and combustion system design), to advanced emissions control utilizing modern electronic control of the fuel injection system and exhaust gas recirculation.

Light-duty diesel trucks. Again, the U.S. EPA defines light-duty diesel trucks much like their gasoline counterparts, based on gross vehicle weight, utility, and off-road operation features. The emission control technology classifications are the same as those for diesel passenger cars.

Heavy-duty diesel vehicles. Although the EPA classification for heavy-duty diesel vehicles is the same as for gasoline vehicles, the characteristics of the vehicles themselves are different. Unlike heavy-duty gasoline vehicles, heavy-duty diesel vehicles are primarily large trucks, with gross vehicle weight ratings of 10 to 40 tons. Therefore, the MOBILE4 emission factors are more representative of large trucks (and buses) than the smaller pickup and van-type vehicles (this is also reflected in the fuel economy estimates). As with the other diesel categories, three levels of control are represented: uncontrolled, moderate control, and advanced control.

Motorcycles. The MOBILE4 emission factors for motorcycles are based on the U.S. motorcycle population. The factors for older, uncontrolled motorcycles reflect emissions from two-stroke and four-stroke engines. The factors for newer motorcycles with non-catalyst emission controls reflect emissions only from four-stroke engines, because U.S. emission control regulations have essentially eliminated two-stroke engines from the market.